

Description

Spiral Or Wave Strip Perforating System

Technical Field

The present invention relates to through tubing perforation guns used to support explosive charges in a borehole to form perforations through which water, petroleum or minerals are produced.

Background Art

This invention is an improvement to prior art phased, through tubing, perforating systems in that it allows for widely varied phasing (i.e., orientation of multiple directional charges at various angles) while allowing for retrieval of the carrier. Prior art phased capsule perforating systems may be generally classified into three categories: (1) the phased frangible base strip (US 4,951,744); (2) the retrievable base strip with frangible retaining means (US 5,095,999); and (3) the phased expendable link (US 5,241,891).

The disadvantages of the first category (illustrated in Figure 1 of the drawings) is that the shattered pieces of the base strip are not retrieved from the well leaving a substantial amount of debris. As a result, one cannot determine if all the charges detonated properly. Also, since the base strip shatters after firing the gun, the strip must be brittle and thereby could break when it is not desirable (e.g. upon conveying in the well).

The disadvantage of the second category (illustrated in Figure 2 of the drawings) is that the base strip is composed of a heavy gauge steel bar that limits possible phasing (normally + 45 degrees, -45 degrees) and that distorts (when the shaped charges are fired) to make retrieval difficult. Also, since only a relatively weak

breakable clip retains the capsule charge to the base strip, it may break when it is undesirable (e.g. upon conveying into the well). The advantage of this system is that it permits some simple phasing (two rows at +/- 45
5 degrees typically), and the strip is rugged and retrievable.

The disadvantages of the third category (illustrated in Figure 3 of the drawings) are that more debris is left in the well and that the system is weak (the pins and
10 links often break when they hit obstructions in the tubing), resulting in use only for simple perforating operations. The main advantage of the third category is that very flexible phasing is possible. This high degree of phasing of the capsules is significant to well
15 productivity in many formation types.

Co-pending application PCT/US95/15230 discloses a perforating gun carrier with a slotted configuration and interior dimensions to enable capsule orientation at selected phases between 0 and 360 degrees. The carrier
20 has a frangible seam that fractures upon detonation to form two retrievable strips, each supported by the conveyance sub for retrieval. The seam is a narrow bridge, formed by slotting the carrier partially, with a cross-sectional area that shatters upon detonation of the
25 shaped charges. The remaining cross-sectional area and strength of each strip is sufficient to assure retrieval after detonation. The strips are preferably nonplanar, arcuate or a segment of a circle in cross section. When the capsule charges are arrayed around many phases, by
30 attaching both front and rear portions of the capsule charges to the nonfrangible regions of the carrier, detonating cords are used for detonation.

Disclosure of Invention

35 The general object of the invention is to provide a gun for well perforating that overcomes the various

disadvantages of the prior art devices with a carrier that produces perforations in a wide degree of patterns, including a 360 degree phase relationship, that does not fragment and that is therefore removable from the well.

5 This object is achieved also with a perforating gun having an elongated mounting having a spiral or selected wave, or non-linear, zig-zag form as seen in a plan view, with an outer surface diameter sized for convenient insertion and removal from a well. The mounting strip
10 has a series of openings spaced in intervals for mounting capsule explosive charges in a phased relationship between 0 and 360 degrees. The cross-sectional area of the mounting strip around each opening is selected to prevent fragmentation of the carrier upon detonation of
15 the charges. The mounting strip is preferably metallic with a selected amplitude and wave length.

 In each opening is an explosive capsule with a hollow cap with a nose for attachment to one of the openings. The cap has an annular, interior thread with
20 a thread run-out of selected width. The explosive capsule has a hollow body having an open end with exterior threads and a width less than the width of the thread run-out in the cap to permit free spinning of the body in the cap after thread makeup for convenient
25 threading and connection with the detonating cord.

 The above as well as additional objects, features, and advantages of the invention will become apparent in the following detailed description.

30 Description of the Drawings

 The novel features believed characteristic of the invention are set forth in the appended claims. The invention itself however, as well as a preferred mode of use, further objects and advantages thereof, will best be
35 understood by reference to the following detailed description of an illustrative embodiment when read in

conjunction with the accompanying drawings, wherein:

Figure 1 illustrates a prior perforating gun of the type that utilizes a frangible base strip;

5 Figure 2 is a prior art perforating gun of the type utilizing a retrievable base strip with frangible retaining means;

Figure 3 is a prior art perforating gun having multi phased expendable links;

10 Figure 4 illustrates the preferred embodiment of the present invention in a frontal view;

Figure 5 is a side elevational view of the Figure 4 embodiment;

15 Figure 6 is a view of the Figure 4 embodiment shown from the top within a casing to be perforated to illustrate the shaped charge orientations and perforations in the casing and geological formation;

Figure 7 is a phase diagram showing the phase relationship of the capsule charges in the Figure 4 embodiment;

20 Figure 8 is a fragmentary, enlarged view of the carrier of the Figure 4 embodiment to illustrate the mounting means and strip configuration;

Figure 8-A is a cross-sectional view as seen looking along the corresponding lines and arrows of Figure 8;

25 Figure 9 illustrates one capsule charge of the type used in the preferred embodiment of Figure 4;

Figure 9-A is an enlarged, fragmentary view taken from Figure 9; and

30 Figure 10 is a plan or frontal elevational view of an alternative embodiment of the mounting means shown in the plane of the paper.

Description of the Invention

35 Referring initially to Figures 1-3 of the drawings, which illustrate three prior art perforating guns, the perforating gun 11 of Figure 1 utilizes a frangible base

strip 13 having plural surfaces 15, 17 upon which are mounted a plurality of capsule charges 19 oriented at different angles or phases to perforate a well in more than one direction. The base strip 13 is constructed of
5 a material as explained in the specification of U.S. Patent No. 4,951,744 to shatter into a multitude of very small pieces in response to detonation of the capsule charges, allowing the resulting debris from the base strip to fall ideally below the perforating zone, to
10 prevent obstruction of the flow of oil or gas from the perforated well. The material of the base strip 13 is strong enough to avoid breakage during impact with an obstruction when travelling downward in the borehole.

A retrievable base strip that will not shatter when
15 the charges detonate, and that may be retrieved from the well, is disclosed in U.S. Patent 5,095,999. Here, the charges are retained on the base strip by support rings that will shatter into a multitude of pieces, allowing the charges to fall to the bottom of the well. This
20 configuration of perforating gun is illustrated in Figure 2 of the drawings and is taken from U.S. Patent 5,095,999. A nonfrangible strip 21 is retrievable from the well after detonation of the capsule charges 23 upon
25 ignition of the detonating cord 25. The capsule charges 23 are retained on the base strip 21 by a plurality of support rings 26 that shatter upon detonation of the capsule charges.

Another prior art perforating gun is shown in U.S. Patent No. 5,241,891 and in Figure 3, wherein the
30 explosive charges 27 are mounted on link carriers 29, and are detonated by ignition of the detonating cord 31. This configuration of perforating gun occupies a small diameter similar to prior art guns in the well while enabling multi-phase orientation of the charges and
35 retrieval from a well.

Referring now to Figure 4 of the drawings and the

- 6 -

preferred embodiment of the present invention, the numeral 33 designates a perforating gun for well perforating having an elongated, spiraled mounting strip 35 having an outer diameter sized for convenient
5 insertion and removal from a well that contains geological formations that are to be perforated to enhance the production of petroleum or other minerals.

The spiral strip 35 is manufactured by utilizing the capabilities of a multiple axis laser milling machine on
10 drawn-over-mandrel (DOM) tubing. The laser mill must have at least the X-axis and rotational capabilities in order to slit the spiral strip. Four (4) strips are manufactured from each full round tube started. The tube is left partially connected until all spiral slits are
15 made over the length of the tube. The partial connection points are later broken apart to yield four (4) separate strips. The threaded holes on the strip are then completed on conventional machine centers.

The perforating gun 33 has at its upper end a
20 connector 37 for mounting on a conveyance sub (not shown) to raise or lower and position the gun at the selected elevation in the well adjacent to the geological formation to be perforated. The strip 35 is connected to a lower end of connector 47 with a plurality of fasteners
25 39 that may be socket head set screws or the equivalent. Secured to the connector 37 is an electrical means 41 (see Fig. 5) adapted to supply electrical energy to a detonating cord 43.

The exterior surface of the strip 35 is cylindrical
30 about a longitudinal axis (not shown) and is formed of a selected metal that forms a helical band with a pitch in a range of 12 to 24 inches. As shown in the cross-sectional view of Figure 8A, a suitable thickness t for the strip is 0.125 inches and the circumferential width
35 W 1.25 inches. At the lower end of the strip is connected a strap 45 to which may be secured a second

- 7 -

spiraled strip 47. There are a series of openings in the
spiraled strip 35 to serve as mounts for a plurality of
explosive capsules 49. These openings are spaced in
intervals along the length of the spiral strip so that
5 they are arranged in a phase relationship to correspond
with the selected perforation pattern in the well.

As shown in Figure 9, each of the explosive capsules
49 has a cap 51 having a threaded nose 53 that engages
the threads 55 of the strip 35. The cross-sectional area
10 of the strip around or adjacent each opening is selected
to prevent fragmentation of the strip 35 upon detonation
of the charge, taking into account the strength of the
material used to form the strip, which in the preferred
embodiment is a strong, ductile and flexible material
15 such as 1018 steel or 304 stainless steel. The cap 51 is
hollow with an interior cavity 57 to receive an explosive
charge and terminate in an angular interior thread 59
having a thread runout 61, as may be better seen in the
enlarged, fragmentary view of Figure 9A.

20 The thread runout 61 is wider than the threads 63
that are formed on the exterior of the open end of a
hollow body 64 that partially contains the previously
described explosive charge. The open end of the hollow
body also has a seal 65 in an annular groove 67 to
25 prevent contamination and degradation of the explosive
charge. The opposite end of the hollow body 63 has a
slot 69 to receive the detonating cord 43 shown in
Figures 4 and 5, which is adjacent a heat-sensitive
firing pin 71 that will detonate the explosive inside the
capsule. A slot 73 receives a retainer clip 75 (see Fig.
30 8) of conventional configuration to secure the detonating
cord in its position adjacent to firing pin 71.

Referring now to Figure 10 of the drawings (and an
alternate embodiment of the present invention), the
35 numeral 101 designates drawn-over-mandrel (DOM) tube
shown in the plane of the paper (not a true plan or

frontal elevational view) from which four (4) non-linear zig-zag mounting strips can be manufactured from each full round of tube with the use of a multiple axes laser milling machine. One such strip 103 is shown with a plurality of apertures 105 over its non-linear zig-zag length, having edges 107, 109 defined by slitting the tubing 101 with the laser mill. The laser mill must have rotational capabilities in order to slit the tubing 101 and form the non-linear zig-zag strip.

The tube is left partially connected until the non-linear zig-zag slits are made over the length of the tube. The partial connection points are later broken apart to yield four (4) separate non-linear zig-zag strips. The apertures 105 on the strip are then threaded and completed.

In the Figure 10 embodiment, the tube 101 is shown as if it were cut longitudinally and rolled into the plane of the paper, appearing to be a rectangle. The circumference is marked in degrees 111 at the bottom of the tube. The degrees are used to define the edges 107, 109 of the strip 103 and their geometric shape. The dotted lines 113 are imaginary lines that are used in designing the shape of the strip 103 and do not appear physically on the tube. The strip 103 is described as being non-linear and in a zig-zag pattern.

Another way to define the strip 103 shape is with reference to wave forms. The strip 103 has a wave form comprised of a first triangular wave having a half wave length l_1 and an amplitude a_1 . This wave intersects and is continued by a second wave having a half wave length l_2 and an amplitude a_2 . The waves can have a variety of forms such as triangular (as shown), square, rectangular or sinusoidal to provide some examples. The waves can be repeating or identical or may have differing lengths and amplitudes as shown.

The wave form is selected to provide the requisite

pattern of apertures 105 in which to mount shaped charge capsules and to maximize the number of strips 103 that may be cut from the tube 101. By cutting the strip 103 from the tube 101, the shaped charges, when mounted in apertures 105 are arranged in a segment of a cylinder (or arc of a circle in a range of preferably 90-120 degrees) to match the cylindrical shape of the wall in the well to be perforated. The apertures 105 are preferably spaced from one another in a range of 12 to 24 inches.

In the preferred example of Figure 10, the material is the same as that indicated for the spiral strip of Figure 4, with a thickness of 0.125 inches. The dimensions for a successful strip are:

W = 1.25 inches
l₁ = 6 inches
l₂ = 12 inches
D = 3 inches
d = 0.5 inches
a₁ = 45 degrees
a₂ = 45 degrees

It should be apparent from the foregoing that an invention having significant advantages has been provided. The spiral strip 35 of Figure 4 can be configured to enable the orientation of explosive capsules in a wide variety of selected patterns, one of which is shown in Figure 6 in which the strip 35 is used to position the explosive capsule 49 and others like it to form perforation 77 through the metal casing 79 and into the geological formation 81. This pattern has a phase relationship as shown in Figure 7 wherein the perforation 77 is indicated by the corresponding point at zero degrees. Moreover, the configuration of the spiral strip, when constructed as indicated above, prevents it from fragmenting or major distortion that would prevent its retrieval from a wellbore after the explosive capsules are detonated. The spiral may be considered to

be a three dimensional and continuous wave in a cylindrical boundary.

5 The non-linear or waved strip 103 of Figure 10 is an alternate way to achieve many of the advantages of the spiral strip of Figure 4. It is especially advantageous when the pattern perforations need not extend 360 degrees. Since plural strips can be formed of one tube 107, manufacturing efficiencies are obtained.

10 While we have shown our invention in only two of its forms, it is not so limited but is susceptible to various changes and modifications without departing from the spirit thereof.



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Claims

1. A perforating gun for carrying a plurality of explosives connecting by a detonating cord to perforate
5 a section of a well in a selected pattern, comprising:
an elongated, spiraled strip having an outer diameter sized for convenient entry and removal from a well;
a series of openings spaced in intervals along a
10 length of the spiraled strip to serve as mounts for the explosives to be arranged in an angular phase relationship to correspond with said selected perforation pattern in the well;
the cross-sectional area of the strip around each
15 opening being selected to prevent fragmentation of the carrier upon detonation of the charges;
whereby the spiraled strip may be positioned in the well, the explosives detonated to create perforations in the selected pattern and the spiraled strip retrieved
20 from the well.
2. The invention defined by claim 1 wherein the exterior surface of said spiraled strip is cylindrical about a longitudinal axis.
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3. The invention defined by claim 2 wherein said spiraled strip is a metallic and helical band with a pitch in a range of 12 to 24 inches.
- 30 4. The invention defined by claim 1 wherein said openings of the spiraled strip are threaded.
5. The invention defined by claim 4 including an explosive capsule charge which comprises:
35 a cap having a threaded nose for engagement with a threaded opening of said spiraled strip;





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the cap being hollow to contain explosive and terminating in an annular, interior thread with a thread run-out of selected width;

5 a hollow body to contain said explosive and having an open end with exterior threads having a width less than the width of the thread run-out in the cap to permit free spinning of the body in the cap after thread make-up;

10 a slot and retainer to receive a detonating cord on a closed end of the hollow body;

whereby the hollow body may be freely spun to align said slot and retainer for convenient threading and connection of the detonating cord with the explosive capsule charge.

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6. A perforating gun for carrying a plurality of explosives connecting by a detonating cord to perforate a section of a well in a selected pattern, comprising:

20 an elongated, non-linear zig-zag strip having a generally tubular wall sized for convenient entry and removal from a well;

25 a series of openings spaced in intervals along a length of the non-linear zig-zag strip to serve as mounts for the explosives to be arranged in an angular phase relationship to correspond with said selected perforation pattern in the well;

the cross-sectional area of the strip around each opening being selected to prevent fragmentation of the carrier upon detonation of the charges;

30 whereby the non-linear zig-zag strip may be positioned in the well, the explosives detonated to create perforations in the selected pattern and retrieved from the well.

35 7. The invention defined by claim 1 wherein the exterior surface of said non-linear zig-zag strip forms





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an arc of a circle about a longitudinal axis.

8. The invention defined by claim 2 wherein said arc is in a range of about 90 to 120 degrees.

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9. The invention defined by claim 3 wherein said non-linear zig-zag strip is metallic and said openings spaced from one another in a range of 12 to 24 inches.

10 10. The invention defined by claim 1 wherein said openings of the non-linear zig-zag strip are threaded to receive shaped charge capsules.

11. The invention defined by claim 1 including an explosive capsule charge which comprises:

15 a cap having a threaded nose for engagement with a threaded opening of said non-linear zig-zag strip;
the cap being hollow to contain explosive and terminating in an annular, interior thread with a thread run-out of selected width;

20 a hollow body to contain said explosive and having an open end with exterior threads having a width less than the width of the thread run-out in the cap to permit free spinning of the body in the cap after thread make-up;

25 a slot and retainer to receive a detonating cord on a closed end of the hollow body;

whereby the hollow body may be freely spun to align said slot and retainer for convenient threading and connection of the detonating cord with the explosive capsule charge.

12. A perforating gun for carrying a plurality of explosives connecting by a detonating cord to perforate a section of a well in a selected pattern, comprising:

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an elongated strip sized for convenient entry and





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removal from a well and in the form of a selected wave.

a series of openings spaced in intervals along a length of the strip to serve as mounts for the explosives to be arranged in an angular phase relationship to correspond with said selected perforation pattern in the well;

the cross-sectional area of the strip around each opening being selected to prevent fragmentation of the carrier upon detonation of the charges;

whereby the strip may be positioned in the well, the explosives detonated to create perforations in the selected pattern and retrieved from the well.

13. The invention defined by claim 7 wherein the exterior surface of said strip forms an arc of a circle about a longitudinal axis.

14. The invention defined by claim 8 wherein said arc is in a range of about 90 to 120 degrees.

15. The invention defined by claim 9 wherein said strip is metallic and said openings spaced from one another in a range of 12 to 24 inches.

16. The invention defined by claim 10 wherein said openings of the non-linear zig-zag strip are threaded.

17. The invention defined by claim 4 including an explosive capsule charge which comprises:

a cap having a threaded nose for engagement with a threaded opening of said non-linear zig-zag strip;

the cap being hollow to contain explosive and terminating in an annular, interior thread with a thread run-out of selected width;

a hollow body to contain said explosive and having an open end with exterior threads having a width less





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- 15 -

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than the width of the thread run-out in the cap to permit free spinning of the body in the cap after thread make-up;

5 a slot and retainer to receive a detonating cord on a closed end of the hollow body;

whereby the hollow body may be freely spun to align said slot and retainer for convenient threading and connection of the detonating cord with the explosive capsule charge.

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